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THE SPECTROHELIOSCOPE AND ITS WORK[1]

PART II. THE MOTIONS OF THE HYDROGEN FLOCCULI NEAR SUN-SPOTS

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ABSTRACT

The purpose of this paper is to describe in detail some of the rapid motions of hydrogen flocculi near sun-spots. The observations, to be discussed in a future article of this series, were made visually by the author with a spectrohelioscope, which in certain respects is better adapted than other instruments for work of this nature.

In the first part of this paper[2] I have described some of the motions of hydrogen flocculi seen with the spectrohelioscope, without going into the details of many observations recorded in my notebooks. The subject is not a simple one, as the diverse views of experienced astronomers on the similar problem of the motions of prominences indicate. Although the results given in the present paper are fragmentary, I hope they may serve in some measure to stimulate future work by observers adequately equipped for either visual or photographic studies.

An examination of the series of spectroheliograms reproduced in Plate IV will show that the most conspicuous phenomena here recorded by Ellerman are two dark ($H\alpha$) flocculi, rapidly changing in form as they are shot outward from a region, in some cases (espe-

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 393.

[2] *Mt. Wilson Contr.*, No. 388; *Astrophysical Journal*, **70**, 265, 1929

cially at 6^h 39^m) appearing as a bright flocculus, on the preceding edge of a large sun-spot.

By way of contrast, another series of spectroheliograms, also taken on Mount Wilson in 1908, may be found in my first paper on "Solar Vortices."[1] A long dark hydrogen flocculus, which had been photographed on several days with comparatively little change of form, lying at a distance of about 150,000 km from a sun-spot, was suddenly drawn toward the spot at a velocity of the order of 100 km/sec. Four spectroheliograms were fortunately taken by St. John during the fifteen or twenty minutes while the rapid inflow was in progress. Such photographs, which are very rarely obtained, leave no doubt regarding the direction of flow or its approximate velocity. But, as my observations with the spectrohelioscope cited below illustrate, they fail to record some of the most important phases of such phenomena whenever the high radial velocities throw parts of the $H\alpha$ line completely off the second slit of the spectroheliograph.

Spectroheliograms of prominences at the limb have been shown by Pettit to indicate accelerating inflow in most cases and outflow in others:

> Occasionally a streamer may be projected from one of the wings away from the spot, or a spike rise from the region of the spot. This is not the normal condition, however.[2]

Evershed, whose long experience with the solar spectroscope and spectroheliograph renders his conclusions of great value, gives a discussion of his work in the Kodaikanal *Memoirs*.[3] After stating that "all our experience at Kodaikanal goes to prove the essential identity of the filaments (long dark flocculi on the disc) and the prominences which have been photographed here" (p. 111), he gives many other conclusions, some of which will be referred to later. Among these one may be cited now: "The prevailing type of prom-

[1] *Mt. Wilson Contr.*, No. 26, Plates XXXVIII and XXXIX; *Astrophysical Journal*, **28**, 100, Plates XI and XII, 1908.

[2] "The Forms and Motions of the Solar Prominences," *Publications of the Yerkes Observatory*, **3**, Part IV, 232, 1925. See also Part I of the present article, *Mt. Wilson Contr.*, No. 388; *Astrophysical Journal*, **70**, 300, 1929.

[3] John Evershed and Mary Acworth Evershed, "Results of Prominence Observations," *Memoirs of the Kodaikanal Observatory*, **1**, Part II, 1917.

inence found above sun-spots is the Rocket, called by Fényi 'Fleckenkrone,' which consists of jets and streamers radiating from the sun-spot."

In this type of prominence, as Fényi showed in 1892, the changes are rapid and the motion outward.

Evershed's general conclusion (p. 123) will also be of interest here: "Sixty thousand Kodaikanal prominences, and eleven thousand from Kenley, and other thousands from Rome, Sicily, Kalocsa, yet we cannot take one prominence and say: This caused it, thus and thus it began, and developed, and ended."

The fact is that the problem, both observational and theoretical, is complicated and important enough to call for the widespread application of any promising devices that may aid in its solution. The score of spectrohelioscopes already constructed or ordered, after the designs given in my last paper,[1] are especially adapted for this work, because they show many prominences on the disk and also at the limb, render visible masses of hydrogen moving at high speeds which are frequently not recorded by the spectroheliograph, and give an instant measure of the radial velocities of their various parts. It should be remembered, however, that the spectroheliograph is much better adapted for recording the forms of most of the flocculi, especially the fainter ones and those of minute and complex structure. The chief uses of the spectrohelioscope are the detection and study of intense and rapidly moving flocculi and the velocity analysis of prominences.

OBSERVATIONS WITH THE SPECTROHELIOSCOPE

The first satisfactory observations of hydrogen flocculi with a spectrohelioscope were made at my Solar Laboratory in Pasadena on January 16, 1924. On January 18 I tried moving the second slits across $H\alpha$ while observing (five slits were then used at each end of the oscillating bar, as described in the paper just cited), and found that the widely different forms of the flocculi corresponding to different wave-lengths could be beautifully seen in this way. On January 22, after further observations by this method, it became evident

[1] "The Spectrohelioscope and Its Work: Part I," *Mt. Wilson Contr.*, No. 388; *Astrophysical Journal*, **70**, 265, 1929.

that it would serve as a very quick and effective means of distinguishing between approaching and receding flocculi. On January 23 vortex phenomena in a spot group were clearly seen and partially analyzed. The next day the distortions of $H\alpha$ near a brilliant eruption on the sun's disk were so pronounced that the forms of dark descending masses could be seen when the second slits were well beyond the extreme (red) boundary of the dark wings of $H\alpha$. On January 25 the eruption was very large and brilliant, and beyond it dark flocculi were descending at high velocities toward the largest spot in the accompanying group. The following day the large eruption had subsided, but a very small brilliant flocculus was seen at $12^h\ 10^m$ P.S.T. on the outer edge of the bridge separating the umbrae of the largest spot. This lasted only a few minutes, after which a long slender dark flocculus appeared, moving outward from the same point, evidently similar in type to the outflowing dark flocculi shown in Plate IV. Small short-lived bright flocculi also developed intermittently near this spot on January 27, where dark vortex structure could also be seen by setting the second slits at the wave-lengths corresponding to the radial velocities of the moving gases.

During this period, though the oscillating slits were still crude and my observations necessarily fragmentary, I could thus appreciate some of the possibilities of the spectrohelioscope, with which I also observed the tips of prominences moving rapidly toward spots at the sun's limb (as in the photographs reproduced by Slocum and Pettit), the remarkable effects of radial velocity in prominences projecting partly beyond the limb and partly (as dark flocculi) upon the disk, and the rapid flow (on Feb. 17) of such a flocculus toward a spot. Passing over some curious observations of radial motion and apparent absorption effects in prominences at the limb, of the appearance of spots in the light of the D lines, of bright eruptive regions observed with nicol and revolving half-wave plate, and of vortices associated with sun-spots, I come to an observation that bears directly upon the subject of this paper. My instrument, not yet completed, had been equipped with a pair of single oscillating slits and a plane-parallel glass plate below them (the "line-shifter" previously described) for setting any part of the $H\alpha$ line or neighboring wave-lengths on the oscillating second slit while the sun was under observation.

I referred in Part I of this paper to a typical dark arch seen on May 31, 1926, near the spot Mount Wilson No. 2571, then not far from the center of the sun. The appearance in the spectroheliosope was approximately as shown in Figure 1, which is copied from a rough sketch in my notebook, made at $2^h\ 40^m$ P.S.T. The spot was at *A* and the small bright flocculus at *B*. The portion of the dark arch *C* was of maximum intensity when the second slit was off the $H\alpha$ line to the violet. As $H\alpha$ was moved across the slit with the line-shifter the following portion of the arch appeared. When the maximum of intensity in the arch reached *D*, the line was nearly central on the second slit. The rest of the arch did not appear until the red side of $H\alpha$ was brought on to the slit. This terminated in a small black head at *E*, which was blackest when the second slit was well beyond the visible wing of the line to the red. This effect was repeatedly observed by turning the line-shifter, but at $2^h\ 55^m$ it was much less marked.

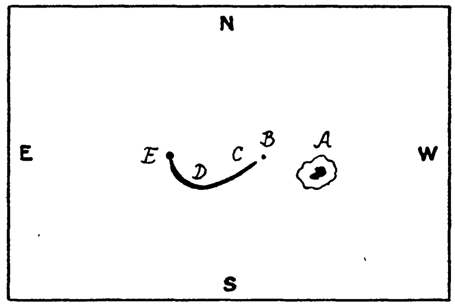


FIG. 1.—Arched flocculus observed on May 31, 1926, near the unipolar spot Mt. Wilson No. 2571.

The inference is plain. Hydrogen, rising from the bright flocculus at *B*, with a radial velocity sufficient to displace $H\alpha$ well to the violet, followed a trajectory which was nearly at right angles to the line of sight at *D* and descended with high radial velocity at *E*. The termination of the arch in a small black head is an interesting phenomenon, frequently observed since that time, especially on the outer edge of the penumbra of spots, at the extremity of an inflowing flocculus.

Such an inflowing flocculus, typical in behavior and important in its bearing on the nature of the currents in the solar atmosphere, was seen in several of its phases on June 26, 1926. When observing at $4^h\ 45^m$ the preceding member of the large bipolar spot Mount Wilson No. 2598 (N 21°, E 26°, approx.), I noticed west of it a strong dark flocculus which I had not seen at 3^h. The glass plate used for a line-shifter was a provisional one, and was not yet equipped with a divided circle. Thus I had to estimate displacements of the slit from the center of $H\alpha$, and as I was not then accustomed to the observation of rapidly changing flocculi, my record is imperfect. Nevertheless, it will serve to give an idea of what to look for in a case of this kind.

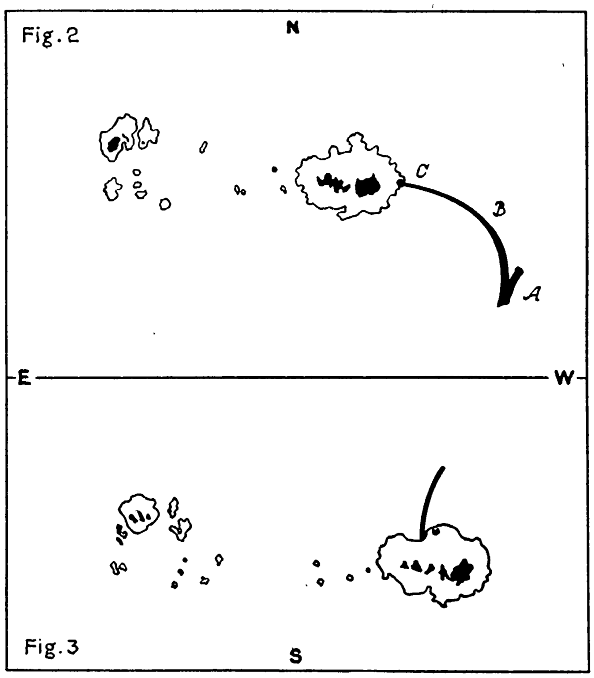


FIG. 2.—Flocculus observed on June 26, 1926, approaching preceding spot of large bipolar group Mt. Wilson No. 2598.

FIG. 3.—Flocculus observed on June 28, 1926, receding from preceding spot of bipolar group Mt. Wilson No. 2598.

At $4^h\ 52^m$, with a second slit half again as wide as $H\alpha$, the flocculus appeared nearly as in the composite sketch reproduced in Figure 2. The outer extremity was most intense when the center of the slit was more than an angstrom from the center of $H\alpha$ toward the violet, and at this slit position the inner end of the flocculus did not reach the penumbra. When the center of the slit was nearly an angstrom to the red of $H\alpha$ the appearance was similar, but the tip now touched the penumbra, though the small black dot noticed later at C was not then seen. Puzzled at first by these phenomena, I soon recognized that the second slit was too wide, and closed it to about half its previous width, or about 0.8 the width of $H\alpha$. At $5^h\ 10^m$, with the slit well beyond $H\alpha$ to the violet, the flocculus had shortened, as though the outer hydrogen had flowed toward the spot. At $5^h\ 18^m$ the whole flocculus was faint with the slit central on $H\alpha$, and became very faint or disappeared at shorter wave-lengths. Three minutes later, with the slit about an angstrom toward the red of the center of $H\alpha$, nothing was observed but a small black dot at *C*, which fell exactly on the outer boundary of the spot's penumbra. After this time a portion of the curved flocculus could be faintly seen by moving toward $H\alpha$ (slit overlapping its red edge). At $5^h\ 34^m$ the black dot on the penumbra appeared to be of maximum intensity at a slit position about half an angstrom to the red of $H\alpha$, and this was the condition at $6^h\ 10^m$, when the rest of the flocculus had practically disappeared (for any slit position).

According to Rowland, the width of the normal dark $H\alpha$ line is 0.963 A, or, including the extreme shading, 1.240 A. Judged from the width of the bright $H\alpha$ at the base of the chromosphere, the shading is actually wider than this. Therefore, a dark hydrogen flocculus without motion in the line of sight may be visible when the second slit, even if extremely narrow, is anywhere within 0.5 or 0.6 A, or even more, from the center of the line.

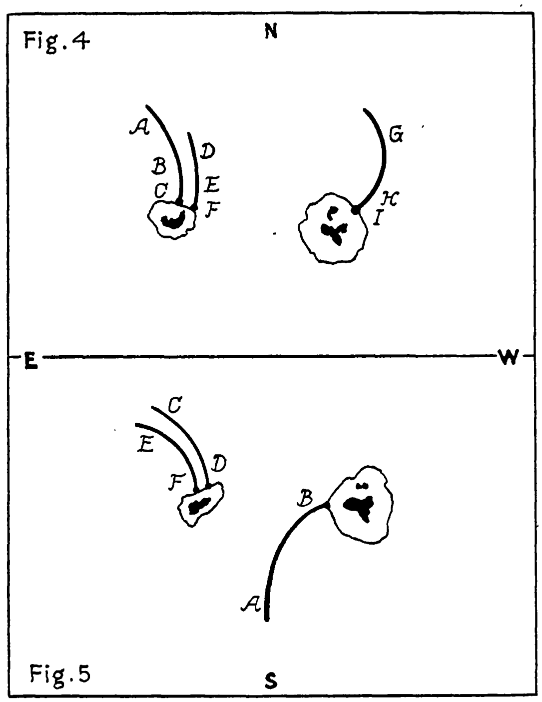
The flocculus appears of greatest intensity when the slit coincides with the position of maximum absorption of the portion of the $H\alpha$ line corresponding to the region in question. If, because of local radial velocity or other cause, this position of maximum absorption is shifted toward red or violet, the second slit must be displaced an equal amount in order to show such parts of the flocculus with maximum contrast. With a wide second slit (on the assumption that the flocculus is exceptionally intense), even those parts moving toward or away from the observer at considerable velocity may be visible at the same time.

With these points in mind it is easy to include the foregoing observations in a single progressive picture. At some time after 3^h an intensely dark flocculus was shot upward near the point *A*. At $4^h\ 45^m$ it was still rising rapidly, but the absorbing gas had been drawn toward the spot and its narrowed tip was already descending toward the outer edge of the penumbra. At $5^h 10^m$ the dark mass at *A* had disappeared and the maximum of intensity had moved about halfway toward the spot to *B*. The outer part of the flocculus continued to fade and by $5^h 21^m$ the maximum of intensity had shifted to the round black dot at *C*, moving downward with a radial component of some 60 km/sec. At $6^h 10^m$ the dot on the penumbra was still black, though apparently descending less rapidly, and the rest of the flocculus had almost completely faded away.

This observation, which recalls the almost unique spectroheliographic results of June 3, 1908, was followed on June 28 by an eruptive outflow from a different part of the same (preceding) spot of the bipolar group. A small bright region appears at the north side of the penumbra of this spot on a direct photograph taken by Ellerman with the 60-foot tower telescope the same morning (June 28, about 6^h). At $10^h 09^m$, I saw with my spectrohelioscope in Pasadena a bright flocculus at this point, when the inner edge of the second slit was just touching the violet edge of $H\alpha$. Eight minutes later a narrow dark flocculus, nearly straight, extended from the same point to a distance about equal to the width of the penumbra of the large spot (Fig. 3). At $10^h 20^m$ only the outer extremity of the flocculus could be seen with the second slit in the same position as in the two previous observations. When the slit was moved farther toward the violet, the maximum of intensity advanced along the dark flocculus toward the spot, ending at the edge of the penumbra. Intermittent renewals of this outflow, bright and dark, appeared later in the day. The hydrogen, rising at intervals from the bright point near the end of the bridge, traveled outward toward the north, reaching its maximum distance at about $3^h 30^m$, at a point where a short, somewhat elongated dark flocculus was seen descending with a radial component of about +60 km/sec.

Omitting various observations of outflow and inflow, made during a period chiefly devoted to experiments with various forms of spectrohelioscopes, we come to some results obtained on August 15, 1926, when improved optical and mechanical parts had been installed and the parallel-plate line-shifter provided with a divided circle for radial-velocity measures. In the first part of this paper one of these inflowing flocculi (here shown as Fig. 4, *GHI*) was illustrated to explain the method of observation, but the others also deserve mention.[1]

The first inflow (Fig. 4, *ABC*) was seen at $10^h\ 15^m$, rising at some distance from the following spot of the pair (Mt. W. No. 2656) and terminating in a small black head descending with moderate velocity toward the outer edge of the penumbra. At $10^h\ 22^m$ another curved



FIGS. 4, 5.—Flocculi observed on August 15 and 16, respectively, approaching both spots of the bipolar group Mt. Wilson No. 2656.

flocculus (Fig. 4, *DEF*) was sketched near the first one. The effect was precisely similar, except that the final black head was descending with higher velocity in this case, and could be seen alone on the edge of the penumbra, when the second slit was well beyond the normal $H\alpha$ line toward the red, at a wave-length where the whole of the first flocculus had disappeared. In both cases, as the line-shifter was rotated, the outer ends of the curved flocculi appeared when the second slit was on the violet side of $H\alpha$ and the maximum

[1] *Ibid.*

of intensity moved steadily along them as the wave-length of the light entering the second slit increased. I was so absorbed in the observations that I forgot to determine the slit zero, and therefore cannot give the radial velocities, though my sketches corresponding to four different line-shifter records show the effects described. At $10^h\ 44^m$ the first flocculus had nearly faded out and *DEF* was weak. At $10^h\ 51^m$ traces of the extremities of both flocculi close to the spot could be seen on the red side of $H\alpha$, but neither flocculus was visible with the second slit on the center of the line.

A still finer effect of inflow, first observed near the preceding spot at $10^h\ 57^m$, which was described (with its radial velocities) in my last paper, is also shown here in Figure 4 (*GHI*).

On the following day a beautiful case of the same kind was observed at $10^h\ 0^m$. A long curved flocculus (Fig. 5, *AB*), originating in a bright eruptive region south following the preceding spot of the same group, terminated in a black head exactly on the following edge of the penumbra, where its radial velocity approached +30 km/sec. A nearly parallel flocculus (not shown in Fig. 5) gave the same effect, which was also given to even better advantage by two parallel curved flocculi (*CD* and *EF*) seen descending toward the following spot at $10^h\ 25^m$. All of these showed the same characteristic appearance, again confirmed on August 17: the apparent advance toward the spot of the inner extremity of the flocculus as the line-shifter was turned so as to bring light of greater wave-length upon the oscillating second slit.

As already remarked, a notable fact, true for all these cases of inflow and for many others since observed, is the termination of each flocculus in a definite black head, usually nearly circular when observed alone well to the red of $H\alpha$, but sometimes accompanied (at the slit position giving maximum intensity) by a short tail. In many instances this head falls precisely above the outer edge of the penumbra of the spot, which is perfectly visible when the second slit is beyond the wings of $H\alpha$. This head, the advance of the maximum of intensity, and the considerable velocity of descent are the most striking features of such phenomena.

On September 11, 1926, having returned to Pasadena after an absence of several weeks, I again confirmed the foregoing effects.

In some instances, as illustrated below, the tip of the inflowing flocculus undoubtedly reaches a point above the edge of the umbra of the spot; but when the second slit is so placed in wave-length as to show the head at its blackest, its center will often be found to lie above the narrow outer boundary of the penumbra. As the seeing in Pasadena is rarely or never good enough to permit the use of high magnifying powers in solar observations, I hope this phenomenon will ultimately be studied minutely elsewhere under more perfect atmospheric conditions.

On September 13 two interesting cases of inflow were observed in conjunction with the spots of a bipolar group, the following member of which was very close to the east limb. A small, curved, dark flocculus was first noticed at $10^h\ 15^m$ just behind the following spot, extending from it to the limb. It could not be seen at circle readings from +10 (red) to −15 (violet), but first appeared at −15 as a dot almost touching the limb. As the line-shifter was turned farther toward the violet a curved extension from this dot approached the spot, appearing as a point on the penumbra when the circle indicated a (tangential) velocity of approach of some 50 km/sec. At $11^h\ 30^m$, just behind the preceding spot of the pair, a flocculus, appearing bright on the disk and extending beyond the limb as a curved prominence, was also seen to be approaching the spot.

I reserve for another section of this paper a discussion of hydrogen vortices in the solar atmosphere, which are usually best studied in their simplest form, associated with single spots.[1] The hydrogen arches and inflows accompanying active bipolar groups, however, often present very striking phenomena, some of which will be described here.

The great bipolar spot group Mount Wilson No. 2686, at about 24° north latitude, was well advanced on the sun's disk when examined with the spectrohelioscope on September 16, 1926. The accompanying outline of the spots was traced from the polarity record made by Nicholson with the 150-foot tower telescope on Mount Wilson at $9^h\ 10^m$, and some of my own later observations of inflowing flocculi have been sketched in at their different positions (Fig. 6).

[1] For a preliminary discussion see "The Fields of Force in the Atmosphere of the Sun," *Nature*, **119**, 708, 1927.

At 12^h 15^m I observed a clearly defined (dark) hydrogen inflow *AB*, which seemed to reach the central umbra of the following spot. Before I could complete a satisfactory set of measures my attention was attracted by a forked flocculus *CD* reaching the preceding umbra in this spot, which it certainly seemed to touch at 12^h 32^m, when its inner end showed a marked radial velocity of recession. The

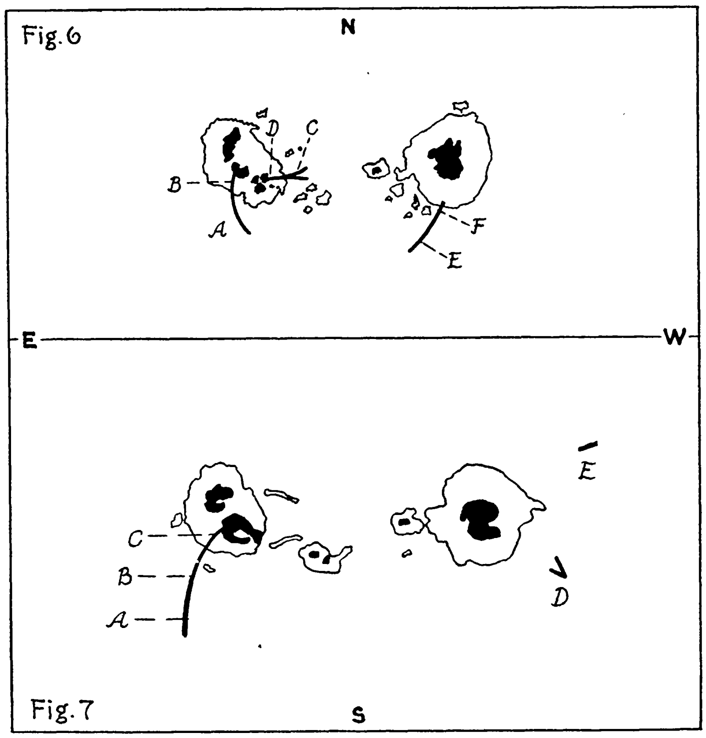


FIG. 6.—Flocculi observed on September 16, 1926, approaching both spots of the large bipolar group Mt. Wilson No. 2686.

FIG. 7.—Flocculi observed on September 17, 1926, near bipolar spot group Mt. Wilson No. 2686.

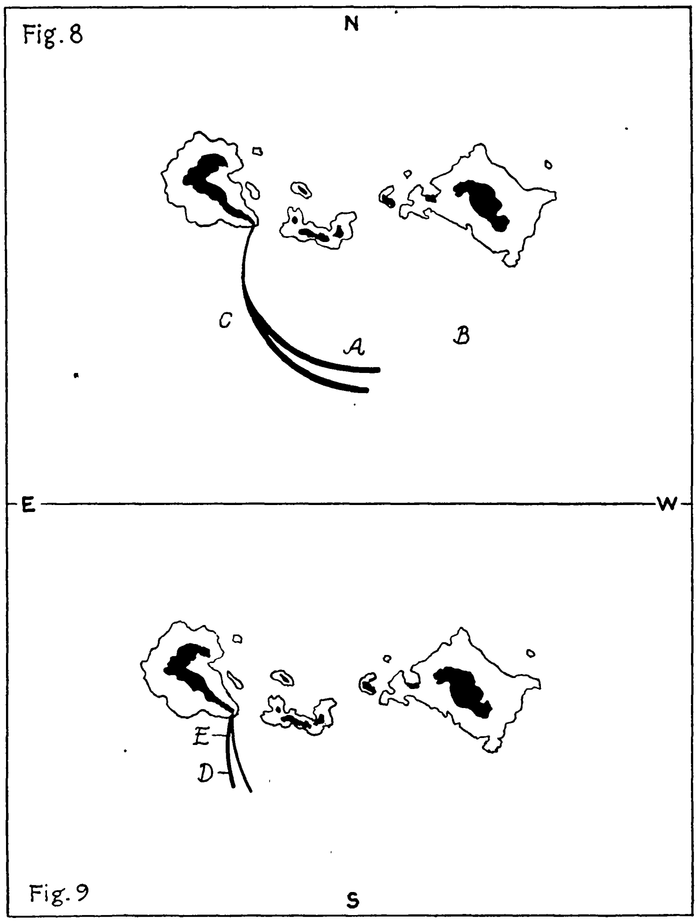
outer forked end *C*, the southern branch of which was darker than the northern, appeared to be nearly stationary in the line of sight. At 2^h 36^m another fainter inflow, which also seemed to reach the umbra, occurred near the same point. Several active bright flocculi appeared at various times during the day between the preceding and following spots of the bipolar group, two of which were very bright at 2^h 58^m, when they gave a width of 1.8 A for $H\alpha$.

At 2^h a dark linear inflowing flocculus *EF* was seen south of the preceding spot. Its outer part *E* was seen alone on the violet side of $H\alpha$. Nearer the spot the radial component reached zero and attained a positive value of some 30 km/sec. in the black, slightly elongated head *F*, which centered exactly upon the outer boundary of the penumbra. This was apparently a case of an arch, composed of absorbing hydrogen, which rose south of the spot and descended toward the penumbra. Later in the afternoon the active bright flocculi fluctuated in intensity, but had disappeared at 5^h. A dark linear arc was then seen, rising near the east boundary of the large preceding spot and descending toward the west umbra of the following spot, but the sun was too low for satisfactory measurements.

On September 17 the same spot group showed some additional cases of inflow, two of which are sketched in Figure 7 on a tracing of the polarity drawing made on Mount Wilson at $8^h 30^m$ that morning by Pettit. At $11^h 05^m$ a very dark linear flocculus, which had not been noticed before, was suddenly seen as a short black line at *A*, with a radial velocity of about -20 km/sec. As the wave-length of the transmitted light was increased by the line-shifter, the flocculus was seen to lengthen toward the spot, though its maximum intensity just outside the penumbra could not be well determined because of a bright flocculus there. A series of measurements was made at six points along the flocculus, however, showing velocities changing from approach to recession, and indicating a faint extension to the central umbra of the following spot at $11^h 28^m$. Two minutes later I found that changes of intensity (for the same wave-length) had occurred near the point *B*, where the radial component was about $+40$ km/sec. At $11^h 35^m$ the tip was noted as apparently reaching the umbra, with a higher velocity of recession. One minute later nothing but a short length at the inner extremity *C* could be seen with the second slit well to the red of $H\alpha$. Another similar inflow, along a closely adjacent path, from a point somewhat farther from the spot, was observed about fifteen minutes later. The values of the radial velocities are uncertain, because the slit zero did not at that time always remain constant, owing to some instability in the parts of the spectroheliosope. No very bright flocculi were then seen in or near the group. At $2^h 32^m$ two short dark flocculi (Fig. 7, *D* and *E*), both rising rapidly, were seen west of the preceding spot. I was called away at that time, and could do no more than to note the fact of their ascent and also that one of them was forked, as indicated roughly in the sketch at *D*, where their positions are only approximate.

On September 18 I observed some of the phases of a striking phenomenon, repeatedly seen in slightly varying form on several successive days. After noting an apparent case of inflow near the preceding spot of the bipolar group, I saw at $11^h 56^m$ a very strong black flocculus *A* with a velocity of approach of about -40 km/sec., which had appeared very suddenly. It showed the beginnings of a forked structure, more fully developed four minutes later, when the general appearance of the flocculus was as shown in Figure 8, at a setting of the line-shifter corresponding to -30 km/sec. The faint curved arc, apparently extending from the point of the fork to the western extremity of the umbra of the following spot, was not seen in the first observation. At $12^h 03^m$, at the same wave-length, the flocculus was noted to be fading. At $12^h 12^m$ the fork, at a setting corresponding to $+16$ km/sec., no longer retained its form or position, but seemed to have split into two faint arcs, with an open space between them, moving in opposite directions toward the preceding and following spots (not shown in the figure, but at the approximate positions *B* and *C*). At $12^h 21^m$ nothing was seen (at any wave-length) excepting the two inflowing flocculi shown at *D* near the following spot in Figure 9 (radial component about $+20$ km/sec.). At $12^h 25^m$ these were fainter and had apparently reached a point above the western tip of the umbra (Fig. 9, *E*, radial component about $+26$ km/sec.). A minute later these flocculi at *E* had disappeared, but another single curved dark flocculus, with a radial component indicating ascent, had arisen at about the position *D*.

Even with the spectrohelioscope, constantly aided by the line-shifter, it is difficult to follow these varying phenomena. Their quick changes in position and wave-length, and the recurrence of new flocculi, rapidly ascending at nearly the same points, show what difficulty there would be in photographing and analyzing them satisfactorily with a spectroheliograph, even with visual guidance by an observer at the spectrohelioscope. As the scale of the photographed image should be large enough to show sharply the slender details of the flocculi, and repeated exposures (necessarily rather long with most existing instruments) must be made at different settings of $H\alpha$ on the second slit, the tasks of photography and measurement

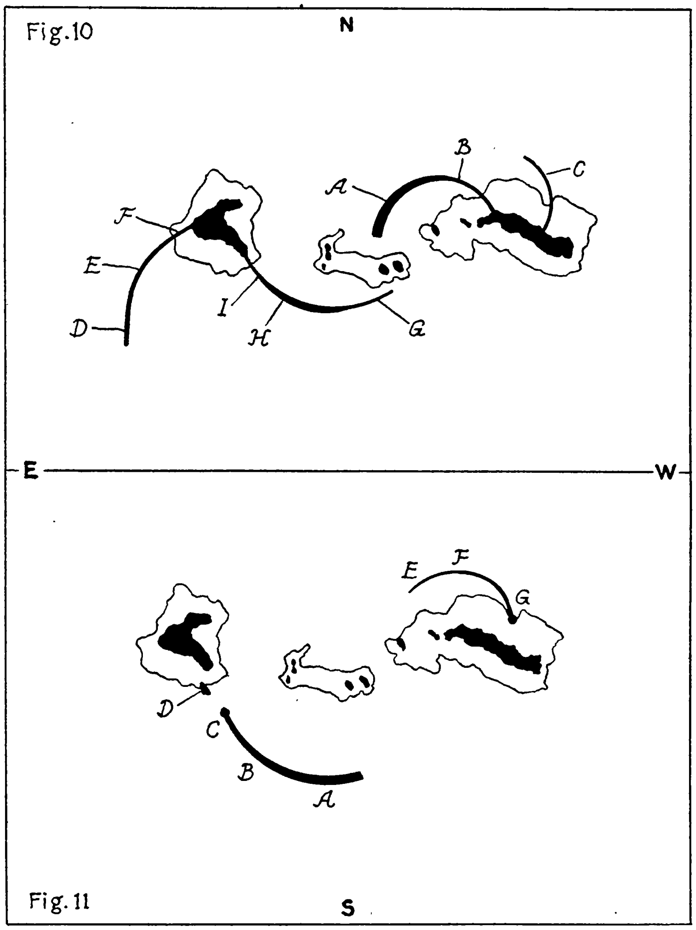


FIGS. 8, 9.—Flocculi observed on September 18, 1926, near bipolar spot group Mt. Wilson No. 2686.

are not easy.[1] On the other hand, it is very difficult with the spectrohelioscope alone to make accurate records of what one readily sees. All of the drawings reproduced in this paper are rough and

[1] I think that an optical combination of comparatively large angular aperture, such as the 40-inch Yerkes refractor and the Rumford spectroheliograph, could be adapted for making good photographic records of the phases of phenomena like those shown in Figs. 8 and 9.

schematic, but they will at least serve to indicate the general character of the phenomena. It is of course to be understood in every case that only a few flocculi of special interest have been picked out for record, though many others were seen; we must turn to the



FIGS. 10, 11.—Flocculi observed on September 19, 1926, near bipolar spot group Mt. Wilson No. 2686.

spectroheliograph for the best means of showing the complex structure of the flocculi always present on the sun.

On September 19 the large bipolar group, as shown by Pettit's polarity sketch at $10^h 45^m$, was crossing the central meridian of the sun (Figs. 10 and 11). Soon after ten o'clock I saw at Pasadena with the spectrohelioscope a strongly marked dark flocculus, not very intense at its inner end, which reached the umbra of the preceding spot (*B*, Fig. 10, radial component from +80 to +100 km/sec.), but broader and very black at its point of maximum intensity (*A*, Fig. 10, radial component +60 km/sec. at $10^h\ 12^m$). A nearly parallel faint slender curved flocculus was seen at $10^h\ 15^m$ near *A*, at a slit position corresponding to a radial component of about +40 km/sec., where the first flocculus at *A* was much fainter. At about the middle of $H\alpha$ both of the parallel flocculi extended farther south than *A* is carried in the sketch. At $10^h\ 26^m$, and again four minutes later, I repeated the observation of the inner tip touching the umbra, and found it very short (reaching only to about *B*) and more intense than at first, with a radial component of about +110 km/sec. The line-shifter was then turned back and forth, permitting the whole length of the flocculus (*A* to umbra) to be repeatedly observed. At $10^h\ 38^m$ it had almost completely disappeared (for any wave-length), though the inner end could be faintly seen, still rapidly descending. Both of the oscillating slits, it may be added, were 0.003 inch wide, less than half the width of the normal dark $H\alpha$ line.

Another faint curved inflow *C*, also descending rapidly and reaching the long umbra of the preceding spot farther to the east, was suspected at $10^h\ 26^m$ and definitely confirmed at $11^h\ 03^m$.

I then turned my attention to the following spot and saw another fine inflow at $11^h\ 12^m$. The maxima of intensity at different parts of the arc corresponded to the following approximate radial components: *D*, +14; *E*, +32; *F*, +54 km/sec. The inner end, which appeared to reach the umbra, was darker than that of the flocculus *AB*. Another inflow *GHI*, showing a greater range of velocity, was noticed at $11^h\ 24^m$, with the following approximate radial components: *G*, +8; *H* (very dark), +26; *I*, +86; tip touching umbra, +114 km/sec. The last measurement was made at $11^h\ 30^m$. Ten minutes later the descending tip at the umbra had about the same radial velocity, but was fainter.

Another inflowing flocculus, which suddenly developed about $11^h\ 50^m$, is shown in a separate sketch (Fig. 11, *AC*), to avoid confusion. At $11^h\ 57^m$ it appeared approximately as from *A* to *B* (very black, radial component about +12 km/sec.) but the black head *C* showed with maximum intensity at +36 km/sec. Four minutes later the black head was seen as a short line *D* on the edge of the penumbra (radial component about +50 km/sec.). In this position of the second slit the outer part *A* could also be seen (indicating a greatly widened $H\alpha$ line at this point), but the intermediate region *B* was invisible. At $12^h\ 01^m$, at a wave-length corresponding to a radial component of +74 km/sec., nothing was visible but a very black dot on the edge of the penumbra. Another very black curved flocculus, seen at $4^h\ 15^m$, flowed toward the following spot, but it faded so rapidly that satisfactory measures could not be made. At one position of the second slit the inner end seemed to reach the umbra, but farther toward the red (radial component about +52 km/sec.) it was seen to terminate as a dot (now fainter) on the edge of the penumbra. At $4^h\ 53^m$ another dot (inflow), with about the same radial velocity, was observed at the same point.

The last inflow seen on September 19 is shown at *EFG*. The outer part *E* was darkest, with a radial component of about −32 km/sec., but farther toward the red (−8 km/sec.), the arc advanced toward the penumbra. Still farther (about +34 km/sec.), nothing remained but the very black point *G*, descending toward the edge of the penumbra.

On September 20 the seeing was better than usual in Pasadena. A well-defined inflowing flocculus *ABC*, sketched in Figure 12 on a tracing of the polarity drawing made by Pettit at $11^h\ 15^m$ the same day on Mount Wilson, was observed at $9^h\ 10^m$ with the spectroheliоscope. Its inner end met the umbra exactly at the end of a narrow bridge recorded in my notes as extending across the umbra (when seen with the light of the continuous spectrum far from $H\alpha$), but not shown in Pettit's later direct image. The tip *C* was descending at $9^h\ 23^m$ toward the umbra with a radial component of about +60 km/sec. Near the center of $H\alpha$ the tip could not be seen, but the part of the arc at *B* (not visible at the previous wave-length) was observed alone. Farther toward the violet were the fainter ascending parallel arcs indicated at *A*, which very likely had previously been more intense, if we may judge from earlier observations of this character. At $10^h\ 13^m$, and also at $12^h\ 08^m$, the tip *C* was visible, again noted as meeting the end of the bridge across the umbra and as very black across the penumbra when the line-shifter indicated a radial component of between +40 and +50 km/sec. At $12^h\ 13^m$ two cases of inflow, having a smaller radial component of recession

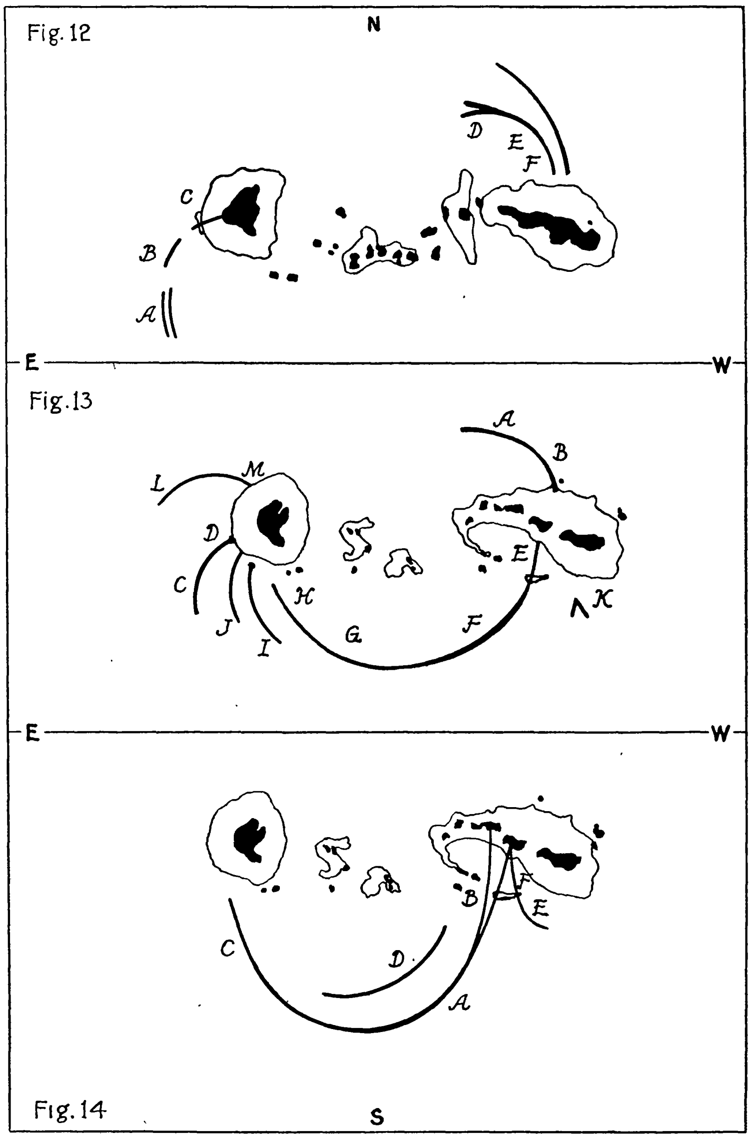


FIG. 12.—Flocculi observed on September 20, 1926, near bipolar spot group Mt. Wilson No. 2686.

FIGS. 13, 14.—Flocculi observed on September 21, 1926, near bipolar spot group Mt. Wilson No. 2686.

at the inner end, were seen reaching the preceding umbra on its north side, near the middle of its length.

In the afternoon, when the seeing was again recorded as exceptionally good, the fine structure of the field of force shown by the less intense flocculi on a spectroheliogram taken at $8^h\ 45^m$ that morning at Mount Wilson was plainly visible, approximately as in Plate V. The curvature of these flocculi on the south side of the preceding spot was noted to be as in the photograph, but no inflow (displacement of the maximum of intensity) could be detected along them with the line-shifter, though definite inflow of the opposite direction of whirl was seen on the north side of the umbra. Two brilliant small flocculi, first detected by my assistant, Mr. Hitchcock, about $12^h\ 30^m$, were recorded at $2^h\ 46^m$ on the penumbra of the preceding spot, a short distance northwest of the western end of the umbra. The width of the bright $H\alpha$ line at these two points was then nearly 1.4 A, or about twice the normal for ordinary bright flocculi. But these bright flocculi, as is so often true, indicated little or no radial motion. At $3^h\ 41^m$ they were decidedly fainter, with a bright $H\alpha$ line about 1 A wide.

At $3^h\ 50^m$, two inflowing curved flocculi were seen north following the preceding spot (Fig. 12, *DEF*). My rough sketch shows them approximately as they appeared five minutes later, when the line-shifter indicated a radial component of about +30 km/sec. At this setting the lower (southern) flocculus was more intense than the northern and forked at the outer end. The northern flocculus, faint at this time at its outer end, was visible alone at about the same setting at $4^h\ 10^m$, when the outer end had become stronger and the southern flocculus had disappeared. When first seen both flocculi extended farther southeast in longer arcs (as observed at the center of $H\alpha$ and to the violet), curving down to reach a line prolonging the preceding umbra to the east.

At $3^h\ 28^m$, and again at 4^h, nearly linear dark flocculi, of a type (to be described later) which appears strong on both sides of $H\alpha$, were seen for short periods southwest of the large preceding umbra.

On September 21, as Nicholson's polarity drawing of the spot group made at $12^h\ 35^m$ shows (Fig. 13), the preceding umbra had divided into several parts. It is interesting to note, though perhaps merely as a coincidence, that two very small spots had appeared on or near its north penumbra, close to the terminations of the dark descending flocculi *FED* in Figure 12. At 9^h I noticed an inflowing curved flocculus (Fig. 13, *AB*), the head of which reached the penumbra, apparently at one of these small spots, with a radial component of about +28 km/sec. Its outer half *A* was seen alone, of maximum intensity at the center of $H\alpha$, where the inner part *B* was invisible. At $9^h\ 16^m$ another inflow (Fig. 13, *CD*) was seen terminating in a black dot (radial component about +34 km/sec.) on the outer edge of the penumbra of the following spot, near the position of the inflowing flocculus seen on September 20 (Fig. 12, *ABC*). Its outer part *C* was of maximum intensity at about −16 km/sec.

A curved dark flocculus (Fig. 13, *EF*), extending from the south and east toward the central umbra of the preceding spot, was observed at $9^h\ 54^m$, but no satisfactory measurements could be made because my instruments were set into vibration by a tractor in motion not far from the Solar Laboratory. The inner end, though faint, seemed to touch the spot when observed at 10^h. Ten minutes later rapid changes of intensity were noted, the part near *F* appearing very dark on the violet side of $H\alpha$. At $10^h\ 31^m$ only the broader and rather fainter section of the arc at *G* was seen (radial component roughly −12 km/sec.). At $11^h\ 13^m$ the arc, as observed at the center of $H\alpha$, included *G* and a narrower extension toward *H*. At $11^h\ 21^m$ (radial component about +8 km/sec.), three or four curved dark flocculi (*H*, *I*, *J*), two of which showed definite inflow, were observed south of the following spot; the maximum of *I* moved toward the penumbra, though it did not reach it ($11^h\ 24^m$), when the line-shifter was turned, while the tip of *J* did reach the penumbra when the circle indicated a radial component of +38 km/sec. Seven minutes later *I* terminated in a black dot just outside of the penumbra, of maximum intensity at +18 km/sec.

It should be added that a small brilliant point flocculus (bright $H\alpha$ about 1.5 A wide) was observed at $10^h\ 36^m$. When examined on the violet side of $H\alpha$ it was seen to be accompanied by two dark wings, which diverged from it, as indicated at *K*.

At $4^h\ 09^m$ another curved flocculus *LM* was seen approaching the large following spot of the pair. Its inner extremity *M* appeared alone as a short, narrow, black line, crossed centrally by the outer edge of the penumbra, with a radial component of about +27 km/sec., while its outer part L was visible without this tip, when the second slit was nearly central on $H\alpha$.

Another sketch (Fig. 14) is needed to show the phenomena noted soon afterward. At $4^h\ 23^m$, on the red edge of $H\alpha$, the slender dark flocculus AB was seen, forked as indicated, the branches extending to the two principal following umbrae of the large preceding spot. Eight minutes later, at a setting near the center of $H\alpha$, the entire arc BAC was visible, accompanied by a shorter arc D. I was unable to make a satisfactory set of measurements, especially as some small bright flocculi appeared within a few minutes south of the preceding spot, about on the line of the western branch of the dark fork. At $4^h\ 49^m$ a dark flocculus EF was found to extend from these bright flocculi to the third umbra in the preceding spot. There were definite signs of inflow, and I was struck by the fact that the direction of the curvature was opposite to that of the arc AB. The seeing was excellent, and there seemed to be no doubt about the reality of these phenomena.

On September 22 the spot group, as shown by Ellerman's polarity sketch made on Mount Wilson at $6^h\ 45^m$, appeared as in Figure 15. At $9^h\ 02^m$ I saw in Pasadena the curved dark flocculus ABC, with a maximum radial component of about +38 km/sec. at the point C on the edge of the penumbra. As the line-shifter was rotated toward the violet the curve lengthened toward B, so that the arc BC was seen at about +20 km/sec. Farther to the violet the head C disappeared and the arc lengthened to A. It was seen at nearly its full length, though not quite reaching the penumbra, at about −6 km/sec. This was at $9^h\ 12^m$. At $9^h\ 45^m$ the inner extremity, from about B to C, was seen near the center of $H\alpha$ to be split from B to C into a fork (similar to that shown in Fig. 14). The arms of the fork were faint but unmistakable at −12 km/sec., but were stronger at +20 km/sec. At $9^h\ 48^m$ both branches terminated on the penumbra at a setting corresponding to a radial component of about +48 km/sec. The preceding branch was very faint, without head, while the stronger following branch ended in a definite pointlike head, precisely on the outer rim of the penumbra.

At this time the seeing was excellent, and the complex structure of the field of force in the flocculi surrounding the group could be

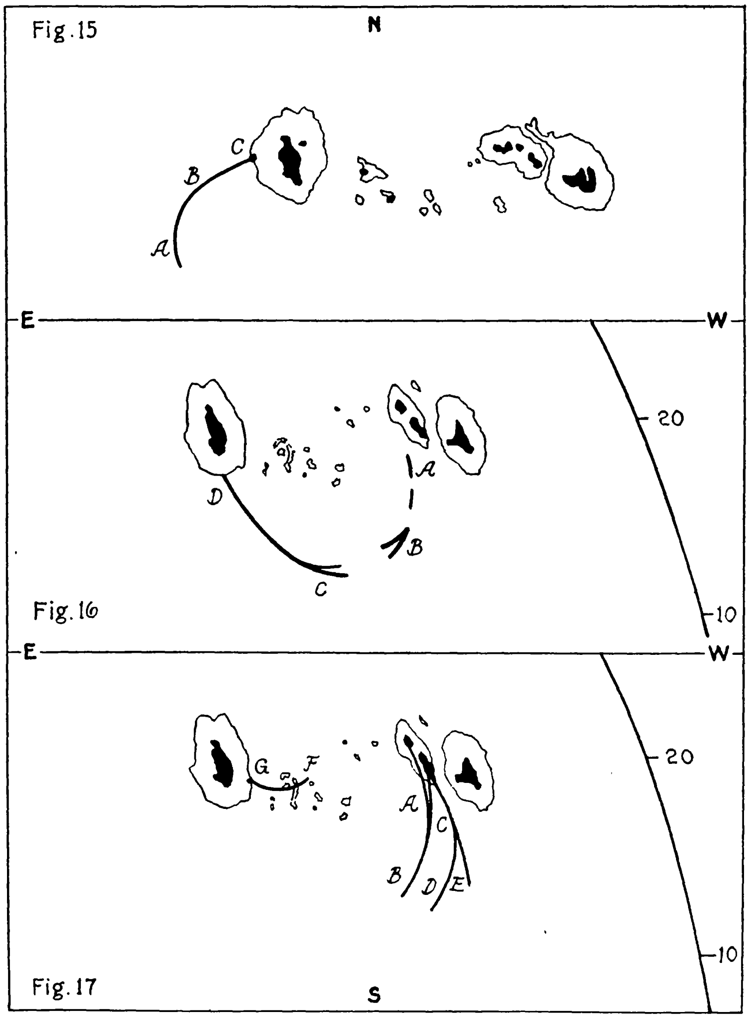


FIG. 15.—Flocculus observed on September 22, 1926, near bipolar spot group Mt. Wilson No. 2686.

FIGS. 16, 17.—Flocculi observed on September 23, 1926, near bipolar spot group Mt. Wilson No. 2686.

seen nearly as well as on the best spectroheliograms. North and south of the following spot the apparently inflowing slender flocculi appeared to be curved in opposite directions (clockwise and counterclockwise), a fact to be noted in my future discussion of the fields of force.

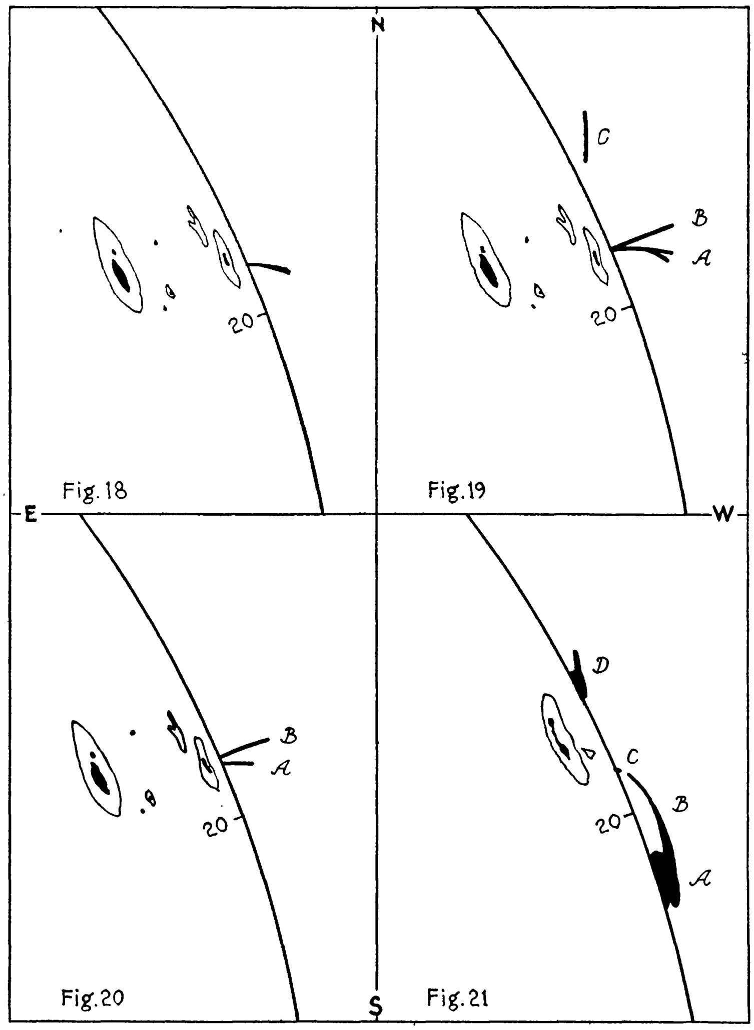
Passing over some other observations, to be mentioned later, we come to the phenomena seen on September 23. The preceding spot was 60° W. and the following spot 41° W. of the central meridian when Ellerman's polarity sketch was made on Mount Wilson at 6^h 36^m. At 10^h 12^m, after recording three fine cases of inflow on the south side of the preceding spots, I saw a long curved flocculus almost reaching the western member of the preceding pair and extending nearly to the following spot of the bipolar group (Fig. 16). The circle reading of the line-shifter was −15 (corresponding to a radial component of about −30 km/sec.), and when this was changed to −20, the maximum of intensity moved out along the arc from *A* toward *B*. At 10^h 38^m two forks not seen before had developed at *B* and *C*, one of which (*B*) was very black with the line-shifter at −23; at this setting only the arc from *B* to *D* was recorded. The forks weakened toward the red and were hardly visible beyond +10. My attention was diverted for a few minutes by another very black flocculus, first noticed at 10^h 31^m north of the following spot at a circle reading of +13, which seemed to originate in a bright flocculus and rapidly extended outward in two branches toward the north. At 10^h 47^m the crown of the arc *BC*, no longer forked, was very intense at −31, but invisible toward the red beyond the center of $H\alpha$. The rest of the arc (*CD*) was faint. At 10^h 56^m the crown of the arc appeared at −15 in two overlapping parts, not forked, the inner one now fading (though somewhat more intense at −19), while the outer arc extended to the western spot of the preceding pair, but disappeared east of *C*. At 11^h 20^m an arc of the opposite curvature (not shown in Fig. 16) was seen extending from a point near the center of the bipolar group toward the north following side of the western spot of the preceding pair.

Another cut (Fig. 17) is needed to show clearly my later observations on the same day. At 12^h 05^m, with the second slit nearly central on $H\alpha$, the three arcs *AB*, *CD*, and *CE* were seen. *AB* was split into a fork, the two branches of which appeared to reach the two umbrae of the western spot of the preceding pair. *DC* and *EC* united at *C*, from which point they continued as a slender dark line to the nearer of these umbrae. Two minutes later, at a circle reading of -19, the fork (from A to the umbrae) was invisible, and the maximum of intensity of the arc was at *B*. The arc extending from *E* through *C* to the other umbra persisted faintly, but the arc *CD* was not seen.

In the afternoon, at $3^h\ 16^m$, the arc *FG* was observed. The outer extremity *F* was seen alone near the center of $H\alpha$. At a circle reading of -6 only the crown of the arc, curving about a small sun-spot, was visible. At $3^h\ 19^m$, when the line-shifter was set at -26, no trace of the arc could be seen excepting the black dot at *G* on the edge of the penumbra of the large following spot.

The arcs south of the bipolar group were renewed on September 24, and on the following day, when the preceding spot had almost reached the west limb, several slender prominences were seen projecting to heights of from 30,000 to 40,000 km. The first of these, observed at $10^h\ 30^m$ with first and second slits 0.006 and 0.004 inch in width, respectively, is shown in Figure 18. It had disappeared within a few minutes, before satisfactory measurements could be completed. At $10^h\ 58^m$ this prominence reappeared at about the same position, somewhat higher and brighter than before. With the comparatively wide slits employed its entire length was visible near the center of $H\alpha$, but the line-shifter showed that the maximum of intensity of its upper part was to the violet of that at the base, implying for its summit a relative motion of approach. At the same time a small brilliant spike, giving a broad, bright $H\alpha$ line, was seen on the disk between the two members of the preceding spot.

At $11^h\ 12^m$ the slender prominence, now apparently higher, was forked, as in *A*, Figure 19. Five minutes later the fork had vanished, and the prominence appeared nearly as in Figure 18 at the center of $H\alpha$; a faint slender arc (*C*, Fig. 19), directed toward the second member of the preceding pair of spots, was also seen to the north. When the line-shifter was turned to admit longer wave-lengths, another slender linear prominence (*B*, Fig. 19) appeared well toward the red. These fleeting phenomena were gone before they could be carefully measured and sketched. At $11^h\ 42^m$ two linear prominences could be seen, as indicated in Figure 20. The southern (*A*) was of maximum intensity near the middle of *Hα* (about +3), while the maximum brightness of the northern one (*B*) was at −24, where *A* was not visible. Similar intermittent phenomena, changing as



FIGS. 18, 19, 20.—Prominences observed on September 24, 1926, near preceding spot of Mt. Wilson No. 2686.

FIG. 21.—Prominences observed on September 26, 1926, between spots of Mt. Wilson No. 2686.

rapidly in intensity and radial velocity, were observed later in the morning, in spite of a very thick atmosphere, the forerunner of a fog.

On September 26, as Ellerman's polarity sketch at $6^h\ 40^m$ shows, the preceding spots of the bipolar group were beyond the limb, while the following spot was approaching it. I cannot attempt to illustrate the rapidly changing prominences seen at the limb with the spectroheliosope on this date, but Figure 21 will serve roughly to indicate the general character of the most significant of them. At $10^h\ 27^m$, after a heavy ground fog had cleared away, I saw at *A* a comparatively low prominence, which already extended toward the spot nearly to *B*, with a minute pointlike tip in advance of the slender extension behind it. About fifteen minutes later the tip had curved down to meet the limb not far from *C*. At this moment I noticed a short bright eruptive spike *D* just north of the spot, characterized by a very broad $H\alpha$ line. I tested the image of the spike given by the edges of this bright line with a nicol prism and half-wave plate, but could detect no evidence of polarization. At $11^h\ 03^m$ the prominence *A* was nearly twice as high as when first seen, but the slender extension *BC* toward the spot had disappeared. Meanwhile, the spike *D* had thrown out toward the north an intensely bright extension, partly overlapped by a bright arch, which had enlarged and grown fainter as it moved away from the spot. At $11^h\ 10^m$ the prominence *A* had begun to develop a new slender extension advancing toward *B*, while an arch overlapping *D* (not shown in Fig. 21) had brightened and lengthened toward the north. Its brilliant top had little or no radial motion, but its lower end, which now curved down nearly to the limb, showed a rapid velocity of recession. At $11^h\ 35^m$ the extension from *A* reached beyond *B* and another smaller prominence similar in form to *ABC* had appeared beneath it. Other changes had occurred, including the formation of an arch extending south from above the spike *B*, with which it seemed to have no connection. Similar rapid changes continued, but at $12^h\ 20^m$ little remained excepting two low prominences at *A* and *D*.

On September 27 a prominence closely similar to *ABC* in Figure 21 was seen at $10^h\ 40^m$, near the same position angle. This is a typical form near sun-spots, which I have often observed with the spectroheliosope. In our photographic records it goes back as far as my early wide-slit photographs of a prominence with the K line of calcium, made at the Kenwood Observatory, Chicago, on October

20, 1891,[1] and the three successive photographs of a prominence, showing the growth of its long slender extension, taken at Kenwood with my first spectroheliograph in 1893 (Plate VII*a*, *b*, *c*). Other Kenwood negatives and many made with the 40-inch Yerkes telescope and the Rumford spectroheliograph show prominences of the same type, some of which have been mentioned in references to the work of Slocum and Pettit.

It is not my purpose to enter here into a detailed examination of the observations described above, as these will be supplemented by other observations and discussed in my next paper on whirls and arches in the solar atmosphere. I wish, however, to emphasize a few conclusions bearing on the effective use of the spectrohelioscope and the nature of the phenomena it discloses.

1. As remarked in one of my early papers on the spectroheliograph, in cases of considerable local motion in the line of sight "the portion of a prominence moving with sufficient radial velocity to produce so large a displacement (i.e., great enough to throw the line completely off the second slit) would not appear in the photograph."[2] This accounts for the absence of large and often very significant portions of prominences and flocculi from spectroheliograms, and illustrates the value of the spectrohelioscope for the study of such phenomena.

2. On the other hand, as such photographs as those reproduced in Plates IV, V, and VI indicate, the spectroheliograph is incomparably superior to the spectrohelioscope for recording most of the intricate details of the $H\alpha$ fields of force surrounding sun-spots. My rough schematic sketches hurriedly made with the latter instrument make no pretense to accuracy, but will serve to show the nature of the velocity analyses of certain outstanding phenomena.

3. The advantages and disadvantages of the spectrohelioscope for velocity measures and thus for the analysis of the flocculi should be borne in mind while observing. Its limitations depend upon the width of the second slit, the dispersion employed, and the nature of the intensity-curve of the $H\alpha$ line. It is important to remember, as already stated, that a flocculus may be seen even when the second

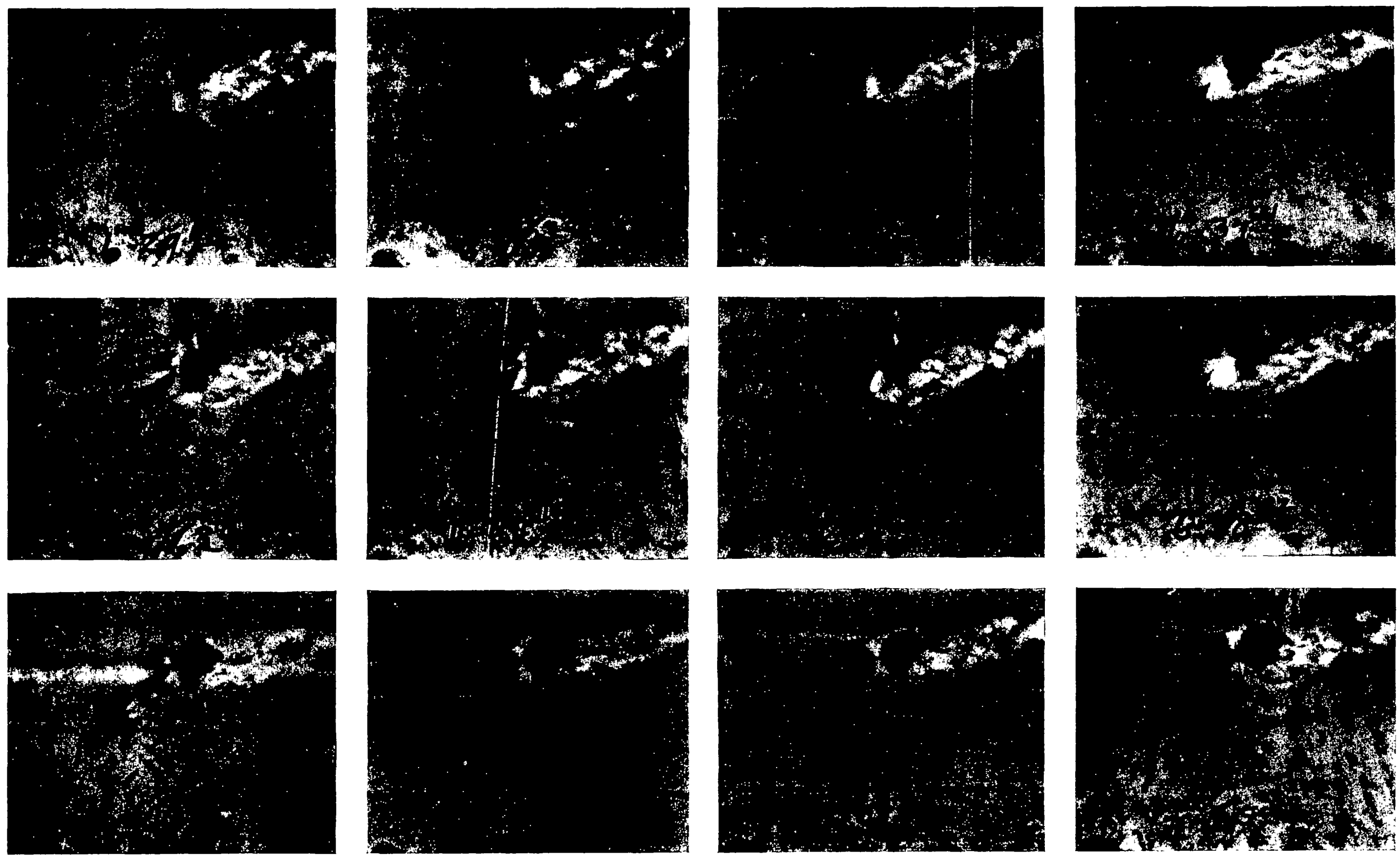
[1] *Astronomy and Astrophysics*, **11**, 77, 1892.

[2] "The Spectroheliograph," *Astronomy and Astrophysics*, **12**, 256, 1893.

slit of the spectrohelioscope falls near the extreme outer edge of its $H\alpha$ line, though it may be very faint under these conditions. On this account, and in view of the fact that the intensity-curve of the line may be materially altered by the physical condition of the absorbing or radiating hydrogen, caution must always be observed in interpreting the results. In general, however, the circle of the line-shifter, when set for a position of maximum intensity, affords a quick and dependable means of analysis.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
January 1930

PLATE IV



RAPIDLY CHANGING FLOCCULI NEAR LARGE SUN-SPOT, SEPTEMBER 10, 1908

PLATE V

BRIGHT AND DARK HYDROGEN ($H\alpha$) FLOCCULI ASSOCIATED WITH THE BIPOLAR SUN-SPOT MT. WILSON NO. 2686

Photographed on September 20, 1926, $8^h 45^m$, by Edison Pettit with the 60-Foot Tower Telescope and 13-Foot Spectroheliograph.

PLATE VI

September 21, 1926, $6^h 40^m$

September 22, 1926, $6^h 49^m$

BRIGHT AND DARK HYDROGEN ($H\alpha$) FLOCCULI ASSOCIATED WITH THE BIPOLAR SUN-SPOT MT. WILSON NO. 2686

Photographed by Lewis Humason with the 60-Foot Tower Telescope and 13-Foot Spectroheliograph.

PLATE VII

a
b
c

THREE SUCCESSIVE PHOTOGRAPHS OF A PROMINENCE

Taken with the Kenwood Spectroheliograph (K line) in 1893